MARINE GEOPHYSICAL INVESTIGATION

In Support Of The

SAN FRANCISCO BAY ROCKS REMOVAL PROJECT

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1. INTRODUCTION

This report presents the results of a marine geophysical investigation conducted by Sea Surveyor, Inc. for the U.S. Army Corps of Engineers, San Francisco District under Contract No. DACW07-98-D-0002. During Fall 2000, Sea Surveyor conducted an intensive geophysical investigation at five (5) offshore sites in Central San Francisco Bay, California. The five offshore sites are underwater geologic features located near the designated ship navigation lanes (Figure 1-1).

Four (4) of the 5 underwater geologic features are bedrock outcrops known as *Blossom Rock*, *Harding Rock*, *Shag Rocks*, and *Arch Rock*. These underwater rock masses extend above -40' elevation, as referenced to the mean lower low water (MLLW) vertical datum, and pose a potential hazard to deep draft shipping.

In general terms, Blossom Rock is located near the North Point of San Francisco, while the other 3 underwater rocks create a 4,000'-wide crescent-shaped navigation hazard west of Alcatraz Island facing the Golden Gate. These three underwater rocks include Harding Rock on the northwest end, Shag Rocks in the middle, and Arch Rock to the southeast. When combined with Alcatraz Island, these underwater rocks create a 9,000'-wide (1.7 mile) barrier to deep draft shipping 2-miles east of the Golden Gate in San Francisco Bay.

The fifth site surveyed by this geophysical investigation is a unique underwater geological feature located about a half-mile closer to the Golden Gate than the crescent formed by Harding Rock, Shag Rocks, and Arch Rock. Nautical Chart #18649 reports this area to be less than 50' deep. The site was originally called "*Unnamed Rock*", but after reviewing the geophysical data, this Report proposes that the name "*Golden Gate Mound*" is more appropriate for this unique underwater geological feature.

Historically, underwater rocks in Central San Francisco Bay have been problematic to navigation since the British Navy sloop "*Blossom*" encountered Blossom Rock in 1826 (Allan, 2001). There have been past efforts to eliminate the hazards to navigation created by these underwater geologic features. Blossom Rock, Harding Rock, Arch Rock and Shag Rocks have historically had their tops removed by underwater blasting. During the period from 1867 to 1869, Blossom Rock was reduced from approximate elevation of -5' MLLW to -24' MLLW. At the beginning of the 1900's, Blossom Rock, Arch Rock, and Shag Rocks had their tops removed to a depth below -30' MLLW. Again in the 1930's, Arch Rock and Shag Rocks had their tops removed to a depth below -35' MLLW and Blossom Rock was lowered to -40' MLLW. In 1932, Harding Rock had its top lowered by blasting to below -35' MLLW.

Recently, the Harbor Safety Committee declared these submerged rocks to be a hazard to deep draft ship traffic. The Committee recommends the lowering or removal of the rocks to decrease the possible threat of a major oil spill in Central San Francisco Bay. The Harbor Safety Committee is comprised of representatives from government, industry, recreation, economic, and environmental groups/agencies as mandated by the State Oil Spill Prevention and Response Act.

In support of the Harbor Safety Committee's recommendation to lower or remove these submerged geologic features, the U.S. Army Corps of Engineers and California State Lands Commission funded this marine geophysical investigation. The purpose of the Geophysical Investigation is to map the rock formations for future rock-core borings and to characterize the rock-mass material properties for engineering analyses.

The marine geophysical investigation included four (4) separate surveys conducted during September, October, and November 2000. The 4 individual surveys conducted at each of the 5 offshore sites in San Francisco Bay included:

- Side-scan sonar and single-beam hydrographic survey — 18-22 September 2000
- Multibeam hydrographic survey — 16-20 October 2000
- Seismic reflection (subbottom profiling) and refraction — 2-5 October 2000
- Marine magnetometer survey — 1-3 November 2000

The schedule for the marine geophysical surveys coincided with the best annual environmental conditions for surveying in Central San Francisco Bay. Typically, the most favorable neap tides, slow currents, and flat seas in Central San Francisco Bay occur every-other week during September, October, and November. The scheduling of the geophysical investigation at bi-monthly intervals allowed the geophysical data to be collected during the most favorable annual survey conditions

This report presents the results and conclusions from the marine geophysical survey. Section 2 describes the field survey methods, equipment, personnel, and analytical techniques used to collect and present the geophysical data. Section 3 discusses the quality assurance/quality control (QA/QC) procedures used to ensure the accuracy of the geophysical data. Section 4 presents the results from the geophysical survey at each of the 5 offshore sites, and Section 6 provides the conclusions from the geophysical investigation. Section 7 is the bibliography, and Section 8 contains compact disks (CD's) filled with the digital data and AutoCAD drawing files.

Separately-bound Appendices contain full-scale charts, side-scan mosaics, and three-dimensional (3-D) perspectives for each offshore site. The full-size charts are divided into five (5) separately-bound appendices, one for each site investigated, including:

- Appendix A: Blossom Rock
- Appendix B: Harding Rock
- Appendix C: Shag Rocks
- Appendix D: Arch Rock
- Appendix E: Golden Gate Mound

Each Appendix has five charts, including: 1) Bathymetric contour chart at scale 1"=100' and three 3-dimensional perspective views, 2) Bathymetric contour chart at scale 1"=50' with multibeam soundings and contours at 5' intervals, 3) Side-scan mosaic at scale 1"=100', 4) Sediment thickness (isopach) chart at scale 1"=100', and 5) Bedrock elevation map referenced to MLLW at scale 1"=100'.

2. FIELD SURVEY METHODS AND ANALYTICAL TECHNIQUES

This section contains a detailed description of the field survey methods, survey vessels and equipment, computer software programs, personnel, and analytical techniques used to collect and process the marine geophysical data.

2.1 SURVEY VESSELS

The use of a proper survey vessel is critical to the success of any marine survey. Sea Surveyor's 25' survey vessel, *BETTY JO*, conducted the majority of the geophysical surveys, including the hydrographic, side-scan sonar, and marine magnetometer surveys. The 43' vessel *DAVID JOHNSTON* conducted the seismic reflection (subbottom profiling) and refraction survey.

The survey vessel *BETTY JO* is a 25' Farallon Whaleback (Figure 2-1) built in 1989 specifically for hydrographic surveying. The *BETTY JO* has an enclosed cabin with work tables and equipment racks, which allows surveying in inclement weather. Onboard 1kw generators supply electrical power. The *BETTY JO* complies with all U.S. Coast Guard safety regulations, and receives an annual Coast Guard inspection. The location of the GPS antenna on the roof of the vessel is directly above the fathometer transducer. The fathometer's 3-degree transducer is located amid-ships (through the keel) of the vessel, near the center of rotation of the vessel. A graph displaying the results from the squat correction test conducted for the *BETTY JO* in January of 1995 is aboard the vessel, per Corps of Engineers' specifications.

The survey vessel *DAVID JOHNSTON* (Figure 2-2) is a 43' vessel owned and operated by University of California, Santa Cruz. The *DAVID JOHNSTON* has a weatherproof cabin with multiple built-in workbenches for the computers, monitors and seismic recorders. The vessel has transducer mounts, cable deployment systems, and a geophysical instrument laboratory specifically designed for conducting comprehensive marine geophysical investigations. A built-in 10kw generator supplies electrical power aboard the vessel. The back deck of the *DAVID JOHNSTON* is 10' x 19', which is ample for deploying the hydrophone arrays. The vessel has a 1-ton A-frame and winch at the stern.

2.2 NAVIGATION AND HORIZONTAL CONTROL

Geophysical data collected during this investigation is referenced to geographic coordinates based on the Global Positioning System (GPS) with differential-corrections. Differential GPS allows sub-meter level accuracies to be routinely obtained. The differential GPS navigation system includes two (2) *TRIMBLE* Model 4000-SSI GPS receivers, with one receiver aboard the survey vessel and a second receiver (called the "base station") set over a horizontal control monument onshore. The onshore GPS base station calculates the differential correction, and transmits the correction to the survey vessel via a radio telemetry system. The *TRIMBLE* 4000-SSI is the most accurate GPS receiver available, and it is capable of determining the location of a moving vessel within $\pm$1m accuracy as referenced to the GPS base station on shore.

The GPS base station was set over one of two horizontal control monuments. For surveys at Blossom Rock, the GPS base station was set over the horizontal control monument "MUNI-7" located at the end of the Muni Pier in San Francisco, California. The California State Zone 3 (NAD-83) coordinates for MUNI-7 is E6,005,761.7' N2,123,376.8' (Lat/Long: N37° 48' 38.56655" W122° 25' 28.07368"). For surveys at Harding Rock, Shag Rocks, Arch Rock, and

Golden Gate Mound, the GPS base station was set over horizontal control point #3354. Control Point #3354 is a first-order horizontal monument established by BESTOR ENGINEERS, INC. at the U.S. Coast Guard Station "Golden Gate" near the north end of the Golden Gate Bridge. The California State Zone 3 (NAD-83) coordinates for horizontal control point #3354 is E5,991,879.4' N2,131,501.8' (Lat/Long: N37° 49' 56.02132" W122° 28' 23.16759").

CORPSCON, a coordinate conversion program developed by the U.S. Army Corps of Engineers, was used to convert coordinates between latitude/longitude to California State Plane and between NAD-27 to NAD-83. The final soundings and all charts presented in this report are referenced to both the NAD-83 California State Coordinate System Zone 3 and NAD-83 latitude/longitude.

Aboard the survey vessel, a navigation computer uses one of two software programs to receive, store and display the navigation and sounding data. The multibeam hydrographic survey uses the navigation software program *HYPACK for Windows Version 8.9*. All other surveys used the navigation software program *TRIMBLE HYDRO*. For both navigation software programs, the computer displays the boat's location on the color CRT screen relative to a pre-plotted trackline. The boat helmsman uses the graphical and digital navigation data as an aid to guide the vessel along the intended survey line.

Data recorded by the navigation computer include event number, date/time, adjusted position coordinates, and uncorrected soundings. The navigation computer also records the quality of the differential GPS positions and other related observations.

The GPS receivers do not use any satellites located less than ten degrees above the horizon in the position computation. The hydrographic software continuously monitors and records the horizontal dilution of precision (HDOP), and the software automatically halts the survey if the HDOP exceeds 5.0. The GPS receivers also monitor the rate of the pseudo-range correctors used for position computation, and stop the survey if the corrections are not received each second.

2.3 BATHYMETRY AND VERTICAL CONTROL

2.3.1 Tide Measurements and Corrections

All soundings collected during the geophysical investigation are corrected for tides and other vertical changes in the water surface. The water surface elevation was measured continuously at three (3) separate locations (Figure 2-3) in Central San Francisco Bay. The soundings are corrected for tides based on the average from the three tide gauges. All soundings are in feet and represent the elevation below Mean Lower Low Water (MLLW) based on the 1960-1978 Tidal Datum Epoch

Sea Surveyor, Inc. monitored tides at two (2) locations, and the National Oceanic and Atmospheric Administration (NOAA) monitored tides at one (1) location. Sea Surveyor monitored tides at Horseshoe Cove and at the end of the San Francisco Municipal Pier. These 2 locations are equal distance (approximately 9,000' west and southeast, respectively) from the survey areas. The tide gauge at Horseshoe Cove is located at the US Coast Guard Station near the north end of the Golden Gate Bridge, and is referenced to Benchmark *BAKER* (elevation 17.03' MLLW or 14.09' NGVD-29). The tide gauge at the Municipal Pier is referenced to *Tidal Benchmark 56* (elevation 12.72' MLLW or 9.73' NGVD-29). The NOAA tide gauge at Presidio provides data via the Internet that correlated the tide data collected at the other two locations by Sea Surveyor, Inc.

Two (2) *CL* pressure-sensing, internally recording tide gauges monitored tides at Horseshoe Cove and at the end of the Muni Pier. The *CL* tide gauge system consists of two pressure sensors. The underwater pressure sensor records changes in the underwater pressure caused by the rising or falling tide, and a second pressure sensor measures and corrects for changes in air (atmospheric) pressure. The tide gauges are calibrated twice daily during the hydrographic surveys, and all of the daily calibrations are within $\pm$0.05' of the tide gauge measurements.

The tide gauges record water surface elevation at 5-minute intervals. Each tide gauge measurement consists of the average of 240 separate water surface elevations recorded at half second (0.5 second) intervals for 2 minutes at the beginning of each 5-minute interval. By averaging the water surface elevation at half second intervals for 2-minutes, the tide gauges can filter out the effects of waves, wakes, and surge.

2.3.2 Single-Beam Hydrographic Survey

During the side-scan sonar survey, an *INNERSPAC*E Model 448 survey-grade fathometer measured water depths using a narrow-beam (3-degree) transducer operating at 200kHz. The *INNERSPACE* fathometer records water depths digitally by transmitting soundings 10-times each second into the navigation computer. The navigation computer records soundings to a resolution of 0.1'. The fathometer also creates a continuous stripchart recording of the water depth. Figures 2-4 and 2-5 show the tracklines from the single-beam hydrographic survey.

Calibration is one of the most critical factors in acquiring accurate sounding data. Calibration of the fathometer occurs at the beginning and end of survey operations each day using the "barcheck" procedure. The bar check procedure consists of lowering an acoustic target (a 12"-diameter circular metal plate) through the boat's sonar hole using a measured sounding line. Adjustments to the speed-of-sound control calibrate the fathometer so that the acoustic target appears on the digital display precisely at its known depth. After calibrating the fathometer for the maximum practical depth, the hydrographic surveyor raises the acoustic target to shallower depths, and records the calibration readings at 5' intervals. The hydrographic data analysis incorporates any variations between the echo sounder trace and the depth of the acoustic target, which yields maximum accuracy in the resulting depth measurements.

Daily post-survey "barcheck" calibrations did not differ from pre-survey "barcheck" calibrations by more than $\pm$0.1' at any of the 5' calibration intervals.

2.3.3 Multibeam Hydrographic Survey

Sea Surveyor, Inc. conducted a multibeam hydrographic survey of five areas in Central San Francisco Bay. The objective of the multibeam sonar survey is to obtain a detailed full coverage bathymetric survey of Arch Rock, Blossom Rock, Shag Rocks, Harding Rock, and Golden Gate Mound. A 2-day mobilization period on October 16-17 provided time to calibrate the multibeam sonar and make quality assurance/quality control (QA/QC) checks. The multibeam sonar collected soundings along over 27 miles of trackline on 18-20 October 2000 to map the bathymetry of the five study areas.

The multibeam hydrographic survey used a *RESON* Seabat 8101 sonar mounted on the 25' survey vessel *BETTY JO* (Figure 2-6). Motion sensors, located at different points on the vessel, record the true motion of the sonar. The multibeam sonar system consists of the following components:

- Multibeam Sonar: The *RESON* Seabat 8101 multibeam sonar consists of the transducer head, an onboard processor, and a video monitor. The transducer mount is on the starboard side of the vessel. An interactive mouse uses the video monitor to adjust system settings such as gain, power, and range. During data collection, the video monitor also shows the acoustic signal from each digitized sonar beam. Seabat data rates vary depending on the depth of measurement and baud rate of the serial line to the data acquisition computer. During this survey, the system was producing between 6 and 7 swaths/second providing 600 to 700 soundings/second. The range resolution of each beam is 0.05'.

- Heave, Pitch, and Roll Sensor: A TSS DMS05 motion sensor is used to monitor and measure sonar roll (rotation port and starboard), pitch (rotation fore and aft), and heave (vertical displacement) during data collection. The DMS05 interfaces to both the Differential Global Positioning System (DGPS) and the SG Brown 1000S gyrocompass to reduce heave error during vessel turns and speed changes. The sensor provides data at a rate of up to 32 Hz at 9600 baud transmit. Manufacturer specifications of accuracy include: Roll/Pitch: Range = $\pm$50 degrees, Accuracy = $\pm$0.03 to 0.05 degrees
  Heave: Range = $\pm$325', Accuracy = 0.2' or 5%, whichever is greater

- Heading Sensor: The SG Brown 1000S gyrocompass monitors vessel and sonar yaw (rotation about the Z-axis) during sonar data collection. High-resolution acoustic surveys require a gyrocompass because of its accuracy (0.5 degree) and its immunity to varying magnetic fields. The SG Brown 1000S updates at a rate of 2 Hz.

- Speed of Sound Measurements: Sound velocity profiles of the water column were recorded several times daily using a *SEABIRD* SBE-19 CTD (Conductivity, Temperature, Depth) recorder. The SBE-19 is a self contained measurement device with internal memory that calculates sound velocity (SV) using the Chen-Millero equations from the measured values of conductivity, temperature, and depth. The profiler records at 2 Hz as it descends to the seafloor and rises back to the surface at a rate of approximately 3'/second. The resulting data represents SVs for every 1.5' of water column.

- Hydrographic Software: The navigation software *Hypack for Windows version 8.9* records the multibeam soundings on a Pentium 533 MHz laptop PC. The laptop computer acquires all multibeam system data (Seabat, motion sensor, gyrocompass, and position) through a Quatec QSP-100 4-port PCMCIA card.

The multibeam hydrographic survey used Class 1 methods and accuracies outlined in the Army Corps of Engineers' HYDROGRAPHIC SURVEYING MANUAL (EM 1110-2-1003, October 1994). Figures 2-7 and 2-8 show the tracklines from the multibeam hydrographic survey conducted on 16 to 20 October 2000. Initially, the multibeam hydrographic survey vessel collected soundings along tracklines spaced at nominal 200' intervals. Spacing the survey lines at 200' intervals provides extensive overlap in the deeper areas, but the shallower areas directly over the rocks need additional lines spaced at nominal 100' intervals to provide complete coverage. In 100' water depths, the multibeam sonar has a swath width of approximately 350' (175' on each side of the vessel), while the swath width is only approximately 120' in 35' water depths directly over the rocks.

Sea Surveyor's experience is that the sonar beams at angles of less than 60 degrees port and starboard collect the highest quality bathymetric data. This limits the swath coverage to approximately 3.5 times the water depth. Sea states during the multibeam survey were always less than 2', and usually less than 0.5'. In these conditions, the boat motion and position sensors accurately measured and compensated all heave, pitch, roll, and yaw motions experienced by the sonar.

After completing the field survey, a hydrographic surveyor processed the multibeam soundings using *Coastal Oceanographic's* HYSWEEP Multibeam Processing and Editing Software. The editing and computer processing of the soundings included the following steps:

1. Sensor Alignment and Calibration Adjustments: The critical roll offset calibration was repeated daily to account for slight variations in the replacement of the motion sensor. Results from each calibration were applied to that survey day's results.

2. Inspection and editing of vessel motion and position data: Satellite coverage and position qualities were dependable throughout the survey. Good quality GPS navigation is when seven (7) or eight (8) satellites are visible and HDOP values are less than 2.
3. Developing tide and sound velocity profile data files: Vertical profiles of sound velocity showed consistent vertical gradients throughout the survey area each day.
4. Merging motion, position, and tide data with Seabat sounding data along a common time base.
5. Editing sounding data manually and/or automatically:
    - Fully resolved soundings were edited both manually and automatically to eliminate spikes and bad returns.
    - Only soundings with acceptable Quality Indexes (QI) were utilized.
    - Soundings at swath angles of greater than 60 degrees were not utilized.
    - Automatic spike filters eliminated 2m or greater jumps in point-to-point soundings.
6. Thinning edited data to desired density:
    - The soundings are thinned to one sounding per 10' x 10' grid. Each sounding shown represents the water depth closest to the center of each 10' x 10' grid square. If no soundings occurred in a particular grid square, the grid is blank.
7. Creating a Digital Terrain Model (DTM) for contour and 3D drawing creation:
    - The 10 ft grid sounding data was used to develop a DTM, bathymetric contours, 3 Dimensional perspectives and geo-referenced TIF map in TerraModel V9.7.
    - Digital 3 Dimensional presentations, in the form of color shaded relief maps were developed from the DTM of each survey area using TerraModel version 9.7 TerraVista 3D Module (V2.03) and Terra Vista Lite.

2.4 SIDE-SCAN SONAR

A side-scan sonar mapped the surficial features and the lateral extent of exposed bedrock at each of the five offshore sites. The surveys, conducted on 18-22 September 2000, used an *EDGETECH* Model 272TD side-scan sonar and a *TRITON-ELICS* Isis computer system. The side-scan sonar was towed 90' and 140' behind the 25' survey vessel *BETTY JO*. The side-scan sonar survey used the same differential GPS system and navigation computer as used in the multibeam survey. The navigation software includes a "layback" program to adjust the GPS coordinates for the distance and bearing of the side-scan towfish behind the boat's GPS antennae.

The *EDGETECH* Model 272TD side scan sonar uses a 100- and 500-kHz transducer to produce a plan view image of the seafloor to the left and right of the survey trackline. The Isis computer is a compact, modular data acquisition and image-processing system that records the digital side-scan images onboard the survey vessel.

The side-scan sonar surveys were run along pre-programmed parallel survey lines, spaced at 150' intervals and oriented in the same direction as the tidal currents over the 5 sites. The side-scan viewed 50m (164') on each side of the trackline, allowing all parts of the seafloor to be viewed from two different directions with 100% overlap. Figures 2-9 and 2-10 show the tracklines from the side-scan sonar survey.

A hydrographic surveyor used the Isis computer system to analyze the side-scan records in the office. The Isis computer system creates a "mosaic" image of the entire survey area by overlapping and displaying the digital side-scan records from consecutive survey lines. The Isis computer produced mosaic images of the side-scan records from each of the five offshore sites. After importing the side-scan mosaics into AutoCAD, coordinates, notes, and Corps of Engineers title block were added.

2.5 SEISMIC REFLECTION (SUBBOTTOM PROFILING)

Seismic reflection surveying, also called subbottom profiling, uses acoustic pulses emitted at regular intervals by an acoustic energy source to image subbottom stratigraphy and geology. The acoustic pulses travel through the water column and reflect off the seafloor and underlying geology or stratigraphy. A surface-towed hydrophone receives the reflected acoustic signals and converts the acoustic pressure waves into electrical signals that are processed and displayed on a graphic recorder in real-time. This display, the subsurface reflection record, is an acoustical profile of the seafloor and subbottom stratigraphy (sediment layers) along the survey trackline. Figure 2-11 is a simplified schematic showing the principles of seismic reflection.

Golder Associates, Inc. collected and analyzed the seismic reflection data under subcontract to Sea Surveyor, Inc., and their results are incorporated within this Report in total without further reference.

The seismic reflection survey of the five offshore sites in Central San Francisco Bay occurred on 2-5 October 2000. During the surveys, a series of transects were run approximately north to south and east to west across the five sites (Figures 2-12 and 2-13). The length of the transects ranged from 500' to 3,600' depending on the particular rock mass and the orientation of the line. The longest transects are oriented parallel to the primary axis of the rock mass. The interval between adjacent transects range from 100' to 400' depending on the line orientation. During the survey, additional transects were added as needed based on information obtained from preliminary analysis of the data. The following list summarizes the coverage for each area:

- Blossom Rock: 13 North-South Lines (2,000' in length)
  8 East-West Lines (1,800' in length)

- Harding Rock: 12 North-South Lines (3,600' in length)
  5 East-West Lines (1,400' in length)

- Shag Rocks: 12 North-South Lines (3,600' in length)
  4 East-West Lines (1,400' in length)

- Arch Rock: 6 North-South Lines (1,400' in length)
  12 East-West Lines (2,200' in length)

- Golden Gate Mound: 9 North-South Lines (2,200' in length)
  9 East-West Lines (1,100' in length)

The geophysical instruments installed on the survey vessel *DAVID JOHNSTON* included:

Datasonic Bubble Pulser	Low Frequency Acoustic Energy Source
Datasonic Receiver	Processing Amplifier/Filter
GeoAcoustic 360	Processing Amplifier/Filter
EPC Model 1086 (2 each)	Dual Channel, Thermal Graphic Recorder
Sony Model PC208A	Sony Model 208 Eight Channel Digital Recorder

The geophysical sensors were tested and calibrated in Emeryville Marina, located approximately 5-miles east of the survey areas, before beginning the survey. In addition, the geophysical technicians ran a complete operational check of all instruments before leaving the dock each morning. The seismic reflection surveys used the same integrated and automated differential GPS system as used in the multibeam hydrographic survey.

A Datasonic Model 1200 Bubble Pulser collected the high-resolution seismic reflection data. This is a medium-frequency (350-800 Hz), low output acoustic energy (20 joules) system that has no adverse effect on fish, but is capable of achieving excellent subsurface penetration, particularly in medium to coarse-grained sediment. On this project, the maximum subsurface penetration achieved with this system was approximately 200' below the seabed.

The hydrophone array was towed 75' astern of the vessel and the Bubble Pulser acoustic source was towed 50' astern. The reflection data was displayed on an EPC Model 1086 thermal graphic recorder and permanently archived on a Sony Model 208A, 8-channel, DAT recorder. The graphic recorder display was set for 200 ms (approximately 500' full scale) and the firing or discharge interval for the acoustic energy sources was 350 milliseconds. The navigation computer placed event marks, at 20-second intervals, on all hard-copy data as well as the data that was stored digitally. These event marks allow a correlation between the seismic data and the vessel position shown on the survey trackline maps.

The analyses of the subbottom profiles included determining the thickness of the sediment overlying bedrock and identifying bedrock exposures. A geophysical technician began the analyses of the subbottom profiles by marking the contact between the sediment and the top of bedrock on all of the records. The geophysical technician measured the thickness of the sediment layer, in milliseconds, at each event number, or in between event numbers if a major change in thickness occurred. The sediment thickness data was entered into an Excel spreadsheet that contained the x,y coordinates for each event. The sediment thickness data was converted into distance by multiplying the travel time by a velocity of 5,000 feet/second. Isopach maps showing the thickness of unconsolidated sediment overlying the top of bedrock are created by plotting and contouring the data in the Excel spreadsheet.

Combining the sediment thickness data with the bathymetric data produced maps showing bedrock elevations. The sum of the two depths, sediment thickness and seafloor elevation, is the elevation of bedrock relative to MLLW. The resolution of the soundings is better than $\pm$0.5', but the resolution of the isopach (sediment thickness) chart is $\pm$2'. A TIN model of the bedrock elevation data contoured the map at 5' intervals, and the resolution of the bedrock elevation map is ±2.5', or half the contour interval.

2.6 SEISMIC REFRACTION

Seismic refraction is a geophysical technique that measures the time it takes for a P-wave generated by an acoustic energy source to travel along interfaces or contacts between different material (seafloor-sediment, sediment-bedrock) of the Earth to a linear array of detectors located in a towed hydrophone array (Figure 2-14). The compressional wave velocity of earth materials can be calculated by measuring the travel time of the sound wave and applying laws of physics that govern the propagation of sound. The compressional velocity information can infer geotechnical characteristics and geology of the subsurface.

The seismic refraction method depends on the condition of an increasing seismic velocity with depth. Seismic refraction can not detect geologic layers that have a seismic velocity slower than the layer above it. Furthermore, refraction may not detect adjacent layers that do not have a significant velocity contrast or that are relatively thin. The total depth of exploration for the seismic refraction method is dependent on the power of the seismic source, length of the hydrophone array and ambient noise conditions. The major sources of noise on this project were from powerboats and ferries, waves and currents, and tow noise.

On 4-5 October 2000, the seismic refraction surveys collected P-wave velocity measurements along several transects in each of the five offshore sites in Central San Francisco Bay (Figures 2-15 and 2-16). Refraction lines were oriented both parallel and perpendicular to the primary axis of each rock mass. On each transect, the energy source was discharged approximately every 200' to 300'. The survey vessel maintained a constant speed, but idled in neutral briefly as the energy source discharged. This provided good coverage over the top of the exposed bedrock surfaces.

A Geometrics Strataview 24-channel digital acquisition system acquired the refraction data. This system digitally stores the refraction data and produces a paper copy in real time. The paper records were used to review and assess the quality of the data acquisition. The energy source for the seismic refraction survey is a Betsy Seisgun using 200 to 250 grain black powder shell that is discharged into the water from a small pipe mounted on the stern of the vessel. An NWGS Model-12 hydrophone array with MP-24 elements spaced at 16' received the refracted acoustic arrivals. The layback to the first hydrophone of the array was varied from 100' to 200'. On the Golden Gate Mound site, where the water was deeper, it was necessary to use a NWGS Model-10 hydrophone with MP-24 elements spaced at 60'. The layback to the first hydrophone was 50'.

Figure 2-17 shows a series of photographs taken during the seismic refraction survey. The array was towed at varying distances astern of the survey vessel and the energy source was discharged immediately off the stern. The survey vessel maintained a slow continuous speed along the selected transects. Just before discharging the energy source, the captain disengaged the boat engine and allowed the vessel to drift along the intended survey line to reduce tow noise on the array. Following each discharge, the boat resumes power and navigates to the next transect while the Seisgun is reloaded.

After completing the survey, a geophysical technician processed the seismic refraction data using Rimrock SIP v. 4.5 refraction software. Expanding and displaying the processed data on a computer terminal made identification of the first arrivals easier, relative to the field paper copies. The geophysical technician selected the first arrivals on the computer and used this information to calculate the velocity of the compressional wave. The reverse refraction line or the bathymetric and seismic reflection data were used to correct for any errors in the calculated velocity resulting from a sloping seafloor or bedrock surface. Printed copies of each record and the first arrival picks verified the data during the quality assurance/quality control (QA/QC) process.

2.7 MARINE MAGNETOMETER

Under a separate task order from the Corps of Engineers, Sea Surveyor conducted a marine archaeological investigation on 2-4 November 2000 in support of the Rocks Removal Project. The marine archaeological investigation included a magnetometer survey of the five offshore areas in Central San Francisco Bay. This report presents the results from the marine magnetometer survey, and the data is also presented in the archaeological report (Allan, 2001).

The presence of ferrous-metal on or below the seafloor was determined using a GEOMETRICS Model G-881 cesium-vapor marine magnetometer. The magnetometer measures variations in the earth's magnetic field using a sensor that is towed 200' behind the survey boat. The navigation computer records the magnetometer at 1-second intervals. The magnetometer has a sensitivity of 1 gamma.

The magnetometer survey used the same 25' survey vessel and differential GPS navigation system used during the hydrographic surveys. Survey line spacing was at nominal 150' intervals. Figures 2-18 and 2-19 show the survey tracklines.

2.8 PERSONNEL

The following geologists, geophysicists and surveyors conducted this geophysical investigation:

Mr. Kennith Harrington, an Engineering Geologist with the U.S. Army Corps of Engineers, wrote the scope of work for this geophysical investigation, provided technical oversight, and reviewed the Draft Report. Mr. Harrington has 28 years experience with the Corps of Engineers. He is presently Geotechnical Section Team Leader for the San Francisco District, and a member of the project delivery team for the San Francisco Bay Underwater Rocks Removal Project. He graduated with a BA from California State University at Fresno in 1967, and has performed post-graduate studies at the University of Missouri at Rolla. He is a registered professional geologist and certified engineering geologist in the State of California.

Steven M. Sullivan is Sea Surveyor's Project Manager for this marine geophysical investigation. Mr. Sullivan oversaw all preparations, fieldwork, and data analysis for this project; therefore, Mr. Sullivan is responsible for the accuracy of the data collected and the quality of all drawings and the report. Mr. Sullivan has a B.S. degree in Oceanography from Humboldt State University, and 23-years experience at conducting hydrographic and geophysical surveys.

Phillip Torres is employed by Sea Surveyor, Inc. Mr. Torres is responsible for the collection and analysis of data for the bathymetric and side-scan sonar surveys. Mr. Torres earned a B.S. degree in Geological Oceanography from Humboldt State University in 1987, and he has 13 years of surveying experience in San Francisco Bay. Mr. Torres produced all drawings and charts prepared for this project.

Craig Martignoni is employed by Sea Surveyor, Inc. Mr. Martignoni was the navigator during the seismic survey conducted for this investigation. Mr. Martignoni is responsible for the setup and programming of all navigation systems on shore and onboard the survey vessels. Mr.

Martignoni also established the benchmarks (vertical control) for this project, and set and calibrated the tide gauges during the hydrographic surveys.

Andrew Hunt is the captain of the 25' survey vessel used during this project. Mr. Hunt possesses a license from the U.S. Coast Guard to operate vessels of up to 100 tons. Mr. Hunt has 15 years experience at operating survey vessels in San Francisco Bay.

Richard Sylwester is a Marine Geophysicist employed by Golder Associates, Inc. Mr. Sylwester was responsible for collecting the seismic reflection and refraction data for this project, and for reviewing and assessing the quality of the seismic data analyzed by Golder Associates. Mr. Sylwester has a M.S. degree in Engineering Geophysics from the University of Washington, and he has over 30 years experience in all aspects of geophysical operations.

Dave Hrutfiord is a Geophysical Technician employed by Golder Associates, Inc. Mr. Hrutfiord assisted in collecting the seismic data, and he provided the initial analyses of the seismic reflection data.

3. QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

A rigorous quality assurance/quality control (QA/QC) program was implemented throughout the geophysical investigation to control, measure, and assess the accuracy of the data collected. This section describes the methods and results from the QA/QC program.

3.1 HORIZONTAL AND VERTICAL CONTROL

3.1.1 Calibration of Electronic Navigation System

To ensure accurate horizontal positioning of the geophysical sensors, Sea Surveyor conducted daily calibration tests of the *TRIMBLE* differential GPS receivers used to provide navigation during the surveys. At the beginning of each survey day, the differential GPS antennae was placed directly over the horizontal control monument "MUNI 7", located at the end of the Municipal Pier. With the differential GPS antennae set over the "MUNI 7" monument, the latitude/longitude coordinates displayed by the navigation computer were compared against the latitude/longitude coordinates reported by the National Oceanic and Atmospheric Administration (NOAA). In all cases, the *TRIMBLE* differential GPS navigation system calibrated to within $\pm$1 meter of the correct coordinate under static conditions.

To ensure that the *TRIMBLE* differential GPS receiver retained its calibration during each survey day, the navigation computer continuously recorded positions from a second differential GPS receiver during the surveys. The second GPS receiver was an *OMNISTAR* Model LR-8 that obtains its differential corrections via satellite from several base stations along the California coast. The coordinates provided by the *TRIMBLE* and *OMNISTAR* differential GPS receivers showed good comparisons, typically matching within $\pm$1-3m.

3.1.2 Vertical Accuracy of Water Surface

There is no local land mass to serve as a base for measuring tides near the 5 survey areas in Central San Francisco Bay, so tides must be inferred from measurements collected miles away. Tides in Central San Francisco Bay have a maximum range from about +8' to -2' MLLW.

During maximum flood and ebb tidal flows (spring tides), the elevation of the water surface in Central San Francisco Bay must change up to 10' during the 6-hours between high and low tide. During maximum tidal flows, the elevation of the water surface at the five offshore sites investigated can be over 1' different than at landbased measurement stations. Periodically, minimal tidal flows occur when high low-tides follow low high-tides. These minimal tidal flows, called *neap tides*, provide an opportunity to accurately interpolate tides between distant gauges.

Any error associated with the elevation of the water level surface directly affects the accuracy of the soundings. To ensure the accuracy of the soundings, it is critical to measure the elevation of the water surface both upstream and downstream of the survey areas.

By scheduling the field surveys at bi-monthly intervals during the Fall of 2000, it was possible to collect the geophysical data during the minimal tidal flows that accompany the neap tides. Sea Surveyor installed two (2) *CL* self-recording tide gauges as close to the project sites as possible. One tide gauge was installed approximately 2-miles downstream of the sites at the north end of the Golden Gate Bridge. A second tide gauge was installed approximately 2-miles upstream of the sites near the North Point of San Francisco (see Section 2.3.1 for detailed discussions). These two installations allowed Sea Surveyor to measure the tidal differences between the two tide gauge locations and across the project site (Figure 3-1). In addition, downloading tidal data from the Internet collected by NOAA at the San Francisco Presidio provides another source for measured tides in Central San Francisco Bay.

During the surveys, the water surface elevation across Central San Francisco Bay was nearly a level plane. During the periods when geophysical data was being collected, water surface elevations at the north end of the Golden Gate Bridge, at the Presidio and at San Francisco's North Point all matched within $\pm$0.2' (Figure 3-2).

The tide gauge at San Francisco's North Point recorded smooth tidal curves that were typically 0.1' higher than those measured near the Golden Gate, but very similar to the tide measured by NOAA at the Presidio. The tides recorded near the north end of the Golden Gate show a tidal surge occurring for up to 2-hours after low tide. The tidal surge near the North End of the Golden Gate Bridge pushes the water level up 0.2' higher than recorded by either the San Francisco tide gauge or NOAA's Presidio tide gauge. However, since all field surveys were conducted during high tide, this tidal surge measured at the Golden Gate after low tide did not contaminate the tidal records.

The soundings are referenced to the MLLW vertical datum using a smoothed tide curve based on the average of the three tide gauges. The smoothed water surface elevation curve used to correct the soundings did not differ by more than $\pm$0.1' from any of the three tide monitoring stations.

A common vertical datum is critical for comparing tide data from stations located miles apart. The tide gauges used for this geophysical investigation were referenced to the most stable and best documented benchmarks located along the San Francisco Bay shoreline. Differential leveling techniques are used to reference the tide gauges to the benchmarks. Differential leveling began at the known vertical control monument (benchmark), proceeded to the tide gauge sites, and then reversed back to the control monument. All surveys closed within $\pm$ 0.04' of the starting elevation.

3.1.3 Bathymetry

Soundings collected during the hydrographic surveys can have an error caused by environmental or electronic factors. Soundings must be corrected for tides, which is accomplished by subtracting the elevation of the water surface, and any error in the tide measurement is carried on into the corrected soundings. Waves, schools of fish, and marine vegetation are some of the many environmental factors that can introduce sounding errors. In addition, any errors in the navigation data cause the soundings to be plotted inaccurately. Therefore, plotted soundings corrected to the MLLW vertical datum have a cumulative error that combines any individual errors associated with navigation, tide measurements, and raw depth measurements. The purpose of this subsection is to measure the cumulative error associated with the individual soundings.

<u>Sound Velocity Profiles</u>: Profiles of sound velocity at various times and places within the five offshore sites are necessary for calculating the speed-of-sound. The hydrographic surveyor collected sound velocity profiles at the beginning and end of the hydrographic surveys at each of the five offshore sites. Numerous sound velocity profiles obtained at various times of the day assured accurate speed-of-sound data for the sonar processing. The hydrographic surveyor repeated each profile as a check on instrument operations. The data corrects for sound velocity and ray path bending in the multibeam sonar data.

<u>Sonar and Sensor Alignment Verification (Patch Test)</u>: The Patch Test is a critical element to reliable and accurate multibeam sonar surveys. The vessel motion and position instrumentation must reflect the true motion of the sonar head, the associated positions and orientations of the sonar beams, and incorporate any timing errors. The relative accuracy of the multibeam soundings are measured using the Patch Test, including:

- Roll offset of the Sonar to the Motion Sensor:
  The roll offset is the most critical of the alignments. To adjust the roll offset, collect soundings along reciprocal survey lines over a flat bottom. Then adjust the roll offset until the resulting soundings statistically match. Offsets ranged from 1.6 to 1.8 degrees during this investigation.
- Pitch offset of the Sonar to the Motion Sensor:
  Measuring the pitch offset requires collecting soundings along reciprocal lines run up and down a slope. No measurable pitch offset was required.
- Yaw offset of the Sonar to the SG Brown Gyrocompass:
  Measuring the yaw offset requires collecting soundings along reciprocal lines run up/down a slope at the same speed so that the lines overlap by approximately half-a-swath width. No measurable yaw offset was determined.
- Navigation latency:
  The time offset between the positioning system and the sonar is determined by running two lines up a slope, one fast and one slow. A latency of 0.5 seconds was determined, which is typical for computerized navigation systems.

<u>Multibeam Soundings vs. Single-beam Soundings</u>: Comparing the soundings from the multibeam survey with the soundings from the single-beam fathometer provide another check on the quality of the hydrographic surveys. Plotting the soundings from the two surveys for each of the five sites on to a single chart allowed point-by-point comparison of the sounding data.

The multibeam soundings represent the closest sounding of many to the center of a 10' x 10' grid, whereas the depth measurements collected by single-beam fathometer are individual soundings.

Due to differences in the two systems, slight variations of the soundings may occur in rugged areas of the seafloor. A hydrographic surveyor examined the combined sounding plots, flagged any discrepancies, and reviewed the causes of the differences. In general, the multibeam soundings matched the single-beam fathometer within ±0.2' in flat areas; however, discrepancies of up to ±2' occurred in areas where large boulders and extreme slopes were encountered.

3.2 QA/QC OF SIDE-SCAN SONAR SURVEY

The QA/QC checkpoints for the side-scan sonar survey included the following items:

- Immediately before beginning the survey, the entire side-scan sonar system (towfish, cable, recorder) was shipped to the manufacturer for calibration of the transmit frequency of the towfish and scale lines on the graphic recorder.

- The "layback" distance that the towfish was being towed behind the GPS antennae on the survey vessel was measured twice each day, and the layback distance was manually-annotated on the navigation log sheets and keyboard-annotated with the digital side-scan records in the navigation computer.

- The "layback" distance that the towfish was being towed behind the GPS antennae on the survey vessel was checked by confirming the horizontal coordinates of one or more significant and easily-recognized seafloor targets that appear on separate survey lines run in opposite directions. Any error in the calculation of the towfish "layback" was recognized, as there will be a difference in horizontal location of seafloor targets viewed from separate survey lines. Corrections for "layback" distances applied during data processing never exceeded ±15'.

- Calibrating the differential GPS navigation system twice daily, including immediately before beginning survey operations and immediately after the completion of survey operations. The accuracy of the differential GPS navigation system was confirmed by placing the GPS antennae over the horizontal control monument "MUNI-7", and manually recording the GPS coordinate and determining any difference between the GPS coordinate and the monument's known coordinate.

- The overall accuracy of the side-scan records is apparent when superimposing the records from consecutive survey lines over one another to create a “mosaic”. Mr. Phillip Torres investigated and corrected any discrepancies found while creating the side-scan mosaic.

- A 3-tier approach was used to interpret the side-scan records. A Senior Geophysical Technician involved with collecting the side-scan data initially interpreted the records and created a draft mosaic of the side-scan records. Mr. Phillip Torres, Sea Surveyor's Data Processing Manager, confirmed the accuracy of the initial interpretation and made any necessary corrections to the mosaic, with input from *Triton-Elics*. Mr. Steve Sullivan, Vice-President of Operations at Sea Surveyor, provided a final review of the side-scan mosaic.

3.3 QA/QC OF SEISMIC REFLECTION (SUBBOTTOM PROFILING) SURVEY

The QA/QC program for the seismic reflection survey was initiated during the planning phase of this project, continued during the field data acquisition phase, and finalized during the in-office data processing and interpretation phase. Mr. Richard Sylwester is the geophysicist responsible for collecting the seismic data. During the survey and at the end of each day, Mr. Sylwester reviewed the seismic reflection data to assure that he could identify the contact between the top of bedrock and the overlying sediment. In addition, the Navigator and Mr. Sylwester reviewed the trackline coverage to be sure that there was more than adequate survey coverage across the main body of the rock masses.

Mr. David Hrutfiord analyzed the seismic reflection data. Mr. Hrutfiord is a geophysical technician that assisted Mr. Sylwester in collecting the field data. Mr. Hrutfiord conducted his analyses after discussions with Mr. Richard Sylwester. These discussions included:

- Review of project proposal with emphasis on deliverables.
- Review of published marine geology and geophysical reports from the area.
- Preliminary review of the reflection records to identify significant features.

After analyses of the seismic reflection data by Mr. Hrutfiord, an independent review of the results was performed for QA/QC purposes, including:

- ➢ The acoustic travel time for selected cross-sections were spot-checked against the interpreted data.
- ➢ The interpreted reflection records were spot-checked against the graphic records.
- ➢ Review of all interpreted results by Mr. Richard Sylwester and
- ➢ An independent review of sediment thickness maps by Mr. Robert Anderson (Senior Geophysicist at Golder Associates) and Dr. Mark Holmes (Geophysicist at the University of Washington).

The final check on the results of the seismic reflection survey is to confirm that the areas of exposed bedrock on the side-scan mosaics match the zero contour on the sediment thickness (isopach) charts. The bedrock elevation charts have the greatest possible cumulative error, because the bedrock elevation charts combine any inaccuracies associated with either the sounding charts and/or the isopach maps.

3.4 QA/QC OF SEISMIC REFRACTION SURVEY

During the seismic refraction survey, the geophysicist preliminarily analyzed the seismic data on the survey vessel using paper records from the seismograph. The purpose for the preliminary analyses was to confirm that arrivals were being received from the bedrock. The geophysicist performed a more detailed analysis at the end of each day using the refraction program in the digital acquisition system.

Dr. John Liu, an experienced geophysicist, conducted analysis of the seismic refraction data. Before analyzing the seismic data, Dr. Liu had detailed discussions with Mr. Richard Sylwester, the geophysicist responsible for collecting the data. These discussions included:

- Review of proposed field survey with emphasis on deliverables.
- Review of published marine geology and geophysical report from the area.
- Preliminary review of the refraction records to identify features that need mapping.

Interpretation and QA/QC of the refraction data consisted of the following:

- ➢ Download the refraction data to processing computer.
- ➢ Enhance and plot all refraction data.
- ➢ Use seismic refraction program to select first arrivals. Check all auto-picks and have results reviewed by Mr. Richard Sylwester.
- ➢ Calculate seismic velocity for unconsolidated sediment and for bedrock.
- ➢ Calculate and plot a depth model and compare to seismic reflection results.

- Review of interpreted data by Mr. Richard Sylwester
- An independent review of refraction velocity profiles by Dr. Michael Maxwell (Senior Geophysicist at Golder Associates) and Dr. Mark Holmes (Geophysicist at the University of Washington).

A critical part of the technical review was the verification of calculations. These were a documented examination by an independent party to confirm the accuracy of calculations. For hand calculations, examination were done by reproducing the calculations as originally performed, or by performing alternate calculations, that produced equivalent results from the same data set. Spreadsheets and other computerized calculations were examined and checked through hand calculations and by an independently derived spreadsheet. Mr. Sylwester repeated selected calculations for confirmation purposes. The calculations selected for re-examination depended on the method of calculations, confidence in the results based on other validity checks, and the extent to which the spot-checking could confirm sequential calculations.

3.5 QA/QC OF FINAL DATA AND DELIVERABLES

Mr. Steve Sullivan (Project Manager), Mr. Phillip Torres (Data Processing), and Mr. Richard Sylwester (Geophysicist) reviewed the draft and final plots of all maps. The San Francisco District, Corps of Engineers received a Draft Report for review and comment. This Final Report incorporates the Corps' comments and recommended changes to the Draft Report.

The final QA/QC check on the report, charts and other deliverables is to contrast and compare the data with previous historical data collected by the U.S. Geological Survey (Carlson, et al., 2000) that is available for downloading from the Internet (Chin, et al., 1998). The purpose of this section is to identify, discuss, and resolve any discrepancies between the historical data and the results from this survey.

The scale of the drawings presented in the USGS study is too large for detailed comparison of the sounding data. Although they were not of the same scale, 30 and 25 meter depth contours are shown in the USGS drawing coincided well with the 100' and 85' depth contours mapped during this investigation.

A comparison of the calculated surface areas of Arch, Harding, and Shag Rocks within the 17m (55.8') contour by USGS in 1998 vs. the 55' contour from this investigation show similar results:

	USGS (55.8' MLLW)	Sea Surveyor (55' MLLW)
Arch Rock	45,000 square meters	42,900 square meters
Harding Rock	18,300 square meters	15,600 square meters
Shag Rocks	17,300 square meters	15,300 square meters

A noticeable difference in the bathymetry at the Golden Gate Mound is evident between the historical data and this investigation. According to the USGS survey, in 1998 the area encompassed by the 65' (20-meter) contour was approximately twice the size as the area presently within the 65' contour.

Table 3-1 compares the minimal (shallowest) depths over the submerged rocks in Central San Francisco Bay against historical data for the five offshore sites investigated. Table 3-1 shows that the soundings collected during this investigation are comparable to the minimum depths shown on NOAA Chart #18649 for Blossom, Harding, Shag, and Arch Rocks; however, Golden Gate Mound is 7' deeper than reported on the nautical chart.

The 1998 USGS survey only included limited side scan sonar data, so there was insufficient data for comparison against the side-scan sonar data collected during this investigation.

TABLE 3-1: Comparison of Minimal Depths over Submerged Geologic Features in Central San Francisco Bay, California. Elevations are referenced to 0.0' MLLW based on the 1960-1978 Tidal Datum Epoch.

	USGS, 1998	NOAA Chart 18649	Sea Surveyor (2001)
Blossom Rock	---	-40'	-39.5'
Harding Rock	-39.4'	-36'	-36.4'
Shag Rocks	-39.4'	-36-37'	-37.5'
Arch Rock	-36.1'	-33'	-36.0'
Golden Gate Mound	---	-48'	-55'

It is possible to compare the results from two (2) seismic reflection (subbottom) profiles from the 1998 USGS seismic reflection study (Carlson, et al., 2000) with the results obtained during this investigation. USGS Line 27P was oriented from the southwest to the northeast over Harding Rock. The profile shows the top of Harding Rock at elevation –62' MLLW, sloping to elevation –262' MLLW on the southwest side of the Rock and down to elevation –272' MLLW on the northeast of the rock mass. The southwest slope is recorded steeper than the northeast slope.

Figure 4-12 in this report presents a profile of Harding Rock in the same orientation as depicted over USGS Line 27P (Carlson, et al., 2000). Figure 4-12 shows the northeast slope steeper than the southwest slope. The discrepancy is due to the difference in the length of the survey lines run. All survey lines for this Geophysical Investigation were confined to the immediate vicinity of the rock masses, as opposed to the 1998 USGS survey lines that extended further.

The second comparable USGS profile is Line 46SK (Carlson, et al., 2000), which was oriented from the northwest to the southeast across both Harding Rock and Shag Rocks. The subbottom profile generated by this investigation in the same orientation (Figure 4-13) is nearly identical to that of USGS Line 46SK. Both profiles show the sediment filled depression between the two rock masses. The thickness of the sediment measures approximately 25' in both profiles.

The 1998 USGS study encompassed a much larger area, with fewer survey lines than this investigation. USGS reports the isopach (sediment thickness) contours in 20-meter intervals, and their data extend far beyond the immediate vicinity of the Rocks (Carlson, et al., 2000). This geophysical investigation was limited to tightly spaced survey lines only in the vicinity of the rock masses; therefore, it is difficult to provide a valid comparison of the two studies.

Since the 1998 USGS report does not contain a bedrock elevation chart, we compared some of the USGS seismic reflection profiles to the Bedrock Elevation Charts presented in this Report. The USGS profile from Line 28P (Carlson, et al., 2000) shows Shag Rocks and the sediment covering its flanks. Figure 4-20 of this report show a similar trend of the southeast slope dipping steeper than the northwest side. Similarly, comparing the profile from USGS Line 149 (Carlson, et al., 2000) with Figures 4-20 and 4-27 in this report reveal similar results; i.e., Shag Rocks is steepest on the south side and Arch Rock is steepest on the north side.

4. SURVEY RESULTS AND DISCUSSION

This section presents the results from the marine geophysical investigation of the five offshore sites in Central San Francisco Bay. Section 4.1 discusses the results from the geophysical survey at Blossom Rock. Appendix A presents full-scale charts of Blossom Rock. Sections 4.2 and 4.3 present data collected at Harding Rock and Shag Rock, with full-size charts of these rocks provided in Appendix B and C, respectively. Section 4.4 discusses Arch Rock, and Appendix D has charts showing the survey results for bathymetry, side-scan, and subbottom profiling. Finally, Section 4.5 describes the unique geological feature that this Report calls Golden Gate Mound, and its full-scale bathymetric contour charts, side-scan mosaics, isopach charts, and bedrock elevation maps are provided in Appendix E.

All horizontal locations presented in this Report are referenced to the California State Plane Coordinate System, Zone 3 (North American Datum of 1983), as well as NAD-83 geographic (latitude/longitude) coordinates. This report references all elevations and depths to the mean lower low water (MLLW) vertical datum. For the purpose of this Report, depths are negative elevations.

Geophysicists from Golder Associates collected and analyzed the seismic data under sub-contract to Sea Surveyor, Inc.

4.1 BLOSSOM ROCK

Blossom Rock is located approximately 4,000' (0.75 miles) north of San Francisco's North Point, and 12,000' (2.25 miles) southeast of the other underwater rock masses. Located near the center of the designated ship channel, Blossom Rock has been problematic to shipping in San Francisco Bay since the British Navy sloop "*Blossom*" encountered it in 1826. Originally, Blossom Rock rose to an approximate elevation of –5' MLLW. In 1869, underwater blasting removed the top of Blossom Rock to below elevation –24' MLLW. In the early 1900's, the top of Blossom Rock was again removed to below elevation –30' MLLW. Blossom Rock was last lowered during the 1930's to about elevation –40' MLLW. Presently, a buoy identified as "BR" marks Blossom Rock.

Hydrographic surveys were conducted over Blossom Rock using both single-beam and multibeam sonar systems. The following figures and full-size charts present the results from the hydrographic surveys of Blossom Rock:

- Figure 4-1 is a bathymetric contour chart of Blossom Rock at scale 1"=200'
- Figure 4-2 shows 3-dimensional views of Blossom Rock as seen from above, the north, and the south.
- In Appendix A, Chart A-1 presents the bathymetric contour chart and three 3-dimensional views of Blossom Rock as imaged from above, the north, and the south at scale 1"=100'.
- Chart A-2 in Appendix A is a bathymetric contour chart (scale: 1"=50') showing soundings at 10' x 10' grid intervals directly over Blossom Rock.

Blossom Rock has a flattened top that rises about 50' above the surrounding seafloor. The top of Blossom Rock has an average elevation of between -44 to -46' MLLW, and a maximum elevation of -30 to -41' MLLW. When soundings are averaged at 10 square foot intervals, the highest point on top of Blossom Rock is at elevation -41.9' MLLW; however, individual soundings within the highest grid interval are as shallow as elevation -39.5' MLLW.

Blossom Rock has a surface area of approximately 100,400 square feet as measured along the -55' contour.

Results from the side scan sonar survey provide a graphic view of the surficial features of Blossom Rock and the surrounding seafloor. In Appendix A, Chart A-4 shows the side-scan sonar records presented as a mosaic at scale 1"=100'. Please note that schools of fish obscure the side-scan mosaic in 6 small areas.

The side-scan mosaics clearly show that Blossom Rock is exposed rock surrounded by unconsolidated sediments. Pockets of sediment are also present on the Rock. Sand waves of 2'-3' amplitude are present on the seafloor to the east and west of Blossom Rock, but finer material blankets the depression on the south side of the Rock. Some rock debris is located southeast of Blossom Rock, near the corner of the survey area.

The most obvious seafloor target shown on the side scan mosaic is the sunken barge that is located approximately 100' south of the edge of Blossom Rock. The sunken barge is approximately 120' long and 30' wide. The barge is laying upright, but tilted, on the seafloor. The sunken barge may be listing to one side because the north side of the barge is 7'-8' above the seafloor while the south side of the barge is nearly flush with the seafloor. Two small targets located a shore distance northeast and southeast of the sunken barge may be anchors partially buried in the seabed. Figure 4-3 shows a close-up of the side-scan image of the west end of the barge.

Figure 4-4 presents the results from the magnetometer survey over Blossom Rock and clearly identifies the sunken barge as a large magnetic anomaly with the possible anchors showing as smaller 20-gamma targets. Another magnetic target located east of Blossom Rock registered as a 20-gamma anomaly, but this magnetic target does not correspond with any images on the side-scan sonar records. The side-scan mosaic does show a 20'-long target located at the extreme south end of the survey area, but this acoustic target does not correspond with any significant magnetic anomalies. A 20' x 20' square block on top of Blossom Rock is visible on the side-scan sonar records, but again this block does not register as a magnetic anomaly. Lack of a magnetic anomaly on an acoustic target suggests that the object on the seafloor contain little or no ferrous metal.

The results from the seismic survey show that Blossom Rock is very symmetrical and drops off steeply on all sides. Figures 4-5 and 4-6 show the seismic record and interpreted cross-section over Blossom Rock in a north-south and east-west direction, respectively.

The following Figures and Charts present the results from the seismic survey over Blossom Rock:

- Figure 4-7 is an isopach map (scale 1"=200') contoured at 5' intervals that shows the estimated thickness of unconsolidated sediment on and around Blossom Rock. Chart A-4 in Appendix A is a full-size chart of isopach contours at scale 1"=100'.

- Figure 4-8 is a bedrock elevation map (scale 1"=200') referenced to MLLW. The bedrock elevation map is contoured at 5' intervals and shows the estimated elevation of the top of bedrock near Blossom Rock. This bedrock elevation map is also presented in Appendix A as a full-size chart at scale 1"=100' (Chart A-5).

The elevation of top of bedrock varies from -40' to -200' MLLW. The sediment, ranging in thickness from 0' to over 150', increases rapidly in thickness to the south of the rock mass.

The compressional velocity measured at Blossom Rock ranges from 10,400 to 11,000 feet/second (Table 4-1).

TABLE 4-1: Compressional Velocities Recorded by the Seismic Refraction Survey at Blossom Rock on 2-5 October 2000.

Array	Easting	Northing	Velocity (ft/sec)
B1	6,012,223'	2,125,712'	10,400
B2	6,012,197'	2,125,929'	10,800
B3	6,012,738'	2,126,018'	11,000
B4	6,012,421'	2,126,018'	10,650
B5	6,012,107'	2,126,019'	11,000

4.2 HARDING ROCK

Harding Rock is the northern-most rock investigated. Harding Rock is located approximately mid-way between three land features, including Alcatraz Island, Angel Island, and the Marin County coastline. All deep draft vessels passing through the Golden Gate must traverse the Bay through the ship channel around the north tip of Harding Rock.

Harding Rock is a potential hazard to navigation because of its proximity to the deep draft ship channel. In 1932, Harding Rock had its top lowered by blasting to below elevation -35' MLLW. A buoy located on the northern tip of Harding Rock marks the edge of the designated shipping channel. The existing buoy is marked "HR".

The following Figures and Charts display the soundings collected over Harding Rock:

- Figure 4-9 is a bathymetric contour chart of Harding Rock at scale 1"=200'.
- Figure 4-10 shows 3-dimensional views of Harding Rock as seen from above, the north, and the south.
- In Appendix B, Chart B-1 presents a bathymetric contour chart and three 3-dimensional views of Harding Rock as imaged from above, the north and the south at scale 1"=100'.
- Chart B-2 in Appendix B is a bathymetric contour chart (scale: 1"=50') showing soundings in a 10' x 10' grid directly over Harding Rock.

Rising about 50' above the surrounding seafloor, Harding Rock is the northwest end of a ridge of bedrock that extends 0.5 miles southeast to Shag Rocks. Harding Rock has a flattened top, with two (2) high spots standing 4-6' higher than the surrounding rock. Most of Harding Rock is below the -40' MLLW contour, but there is a 250' x 75' area on top of Harding Rock that is above elevation -40' MLLW. The highest elevation measured on top of Harding Rock was -36.4' MLLW.

The surface area of Harding Rock above elevation -55' MLLW is approximately 170,300 square feet.

The north slope of Harding Rock is steepest, and several 8' high pinnacles are located along the eastern edge of that slope. The deepest area surveyed is below -100' MLLW on the south side of Harding Rock.

In Appendix B, Chart B-3 shows the side-scan sonar records presented as a mosaic at scale 1"=100'. The side scan mosaic shows Harding Rock to be approximately 600' x 1,200' of exposed rock that rises from the overlying sediment in San Francisco Bay. Coarse-grained sediment create high-amplitude sand waves on the seafloor north and south of Harding Rock, but fine-grained sediment leave a smooth bottom northwest and northeast of the Rock. A seafloor target located at the southeast corner of Harding Rock may be a sunken buoy, but this target has no magnetic signature.

Figure 4-11 shows the results from the magnetometer survey over Harding Rock. The only magnetic target on or near Harding Rock is the existing buoy, identified as "*HR*" that marks the boundary of the ship channel.

The seismic survey over Harding Rock generated a grid of subbottom cross-sections that were interpreted and contoured to create maps showing the thickness of sediment overlying rock (isopach map) and a contour chart of bedrock elevation. Figures 4-12 and 4-13 show representative seismic cross-sections over Harding Rock. Figure 4-12 shows a northwest-oriented seismic cross-section across the short-axis of Harding Rock. A longer seismic cross-section (Figure 4-13) shows the 0.5 mile continuous ridge of bedrock with overlying sediment between Harding Rock and Shag Rocks.

The following Figures and Charts present the results from the seismic survey over Harding Rock:

- Figure 4-14 is an isopach map (scale 1"=200') contoured at 5' intervals that shows the estimated thickness of unconsolidated sediment on and around Harding Rock. These isopach contours are also presented in Appendix B as a full-size chart at scale 1"=100' (Chart B-4).
- Figure 4-15 is a bedrock elevation map (scale 1"=200') referenced to MLLW. The bedrock elevation map is contoured at 5' intervals and shows the estimated elevation of the top of bedrock near Harding Rock. This bedrock elevation map is also presented in Appendix B as a full-size chart at scale 1"=100' (Chart B-5).

The sediment thickness on the Harding Rock mass varies from 0' to over 100' (Figure 4-14). The isopach contours are oriented northwest to southeast which is also the predominant orientation of the rock mass. The rock mass drops off relatively fast along the northeast flank (Figure 4-12). A 25' thick layer of unconsolidated sediment separates Harding Rock from Shag Rocks (Figure 4-13). The elevation of the top of bedrock varies from approximately -40' (exposed bedrock) to over -200' MLLW (Figure 4-15).

The compressional velocity of the bedrock, based on the seismic refraction data, varies from 10,000 to 10,600 feet/second (Table 4-2). A thin layer (5' to 20' thick) of rock debris, and coarse-grained material on the northeastern flank of Harding Rock has a compressional velocity of 8,500 feet/second.

TABLE 4-2: Compressional Velocities Recorded by the Seismic Refraction Survey at Harding Rock on 2-5 October 2000.

Array	Easting	Northing	Velocity (ft/sec)
H1	5,999,506'	2,133,290'	10,100
H2	6,000,265'	2,133,235'	8,500
H3	5,999,528'	2,132,879'	10,000
H4	5,999,879'	2,132,971'	10,600
H5	6,000,062'	2,132,812'	10,600

4.3 SHAG ROCKS

Shag Rocks is the center of three rock masses that create a 4,000'-wide crescent-shaped navigation hazard facing the Golden Gate. Shag Rocks is the southeast end of a 0.5-mile long ridge of bedrock that extends to Harding Rock. Shag Rocks is located about 1,800' (0.34 miles) north of Arch Rock, and about 4,500' (0.85 miles) northwest of Alcatraz Island.

Shag Rocks has had its tops removed twice by underwater blasting; first in the early 1900's to an elevation below -30' MLLW, and again in the 1930's to an elevation below -35' MLLW.

The results from an intensive hydrographic survey over Shag Rocks using both multibeam and single-beam survey-grade fathometers are presented in the following Figures and Charts:

- Figure 4-16 is a bathymetric contour chart of Shag Rocks at scale 1"=200'.
- Figure 4-17 shows 3-dimensional views of Shag Rocks as seen from above, the east, and the south.
- In Appendix C, Chart C-1 presents the bathymetric contour chart and three 3-dimensional views of Shag Rocks as imaged from above, the east and the north at scale 1"=100'.
- Chart C-2 in Appendix C is a bathymetric contour chart (scale: 1"=50') showing soundings in a 10' x 10' square grid directly over Shag Rocks.

Shag Rocks consist of two (2) flattened mounds of rock atop a rock mass rising about 50' above the surrounding seafloor. The two flattened mounds on top of Shag Rocks are above elevation -40' MLLW. A 5'-deep depression separates the two flattened mounds. The highest point on each of the two mounds is at elevation -37.5' MLLW. Numerous pinnacles of 5-20' height are distributed on the south and west flanks of Shag Rocks. The side scan mosaics show boulders and large rock debris surrounding the flattened tops on Shag Rocks. Water depths increase to over 100' on the western corner of the survey area.

The surface area of Shag Rocks above elevation -55' MLLW is approximately 164,600 square feet.

In Appendix C, Chart C-3 shows the side-scan sonar records presented as a mosaic at scale 1"=100'. The side scan mosaic of Shag Rocks shows exposed bedrock rising from the unconsolidated sediment of San Francisco Bay. Medium- to high-amplitude sand waves surround Shag Rocks, which is indicative of coarse-grained sediment.

Figure 4-11 presents the results from the magnetometer survey over Shag Rocks. The largest magnetic anomaly found on or near Shag Rocks is a 10-20 gamma target located south of Shag Rocks in approximately 95' of water. The side scan mosaic does not show an acoustic target at the location of the magnetic anomaly; therefore, the unconsolidated sediment probably covers the ferrous metal causing the magnetic anomaly. Two small 10-gamma magnetic anomalies on top of Shag Rocks coincide with two possible targets shown on the side scan mosaic.

Cross-sectional subbottom profiles from the seismic survey provide a grid of information on the subsurface geology over Shag Rocks. Figure 4-18 presents a representative subbottom profile across Shag Rocks. Figure 4-13 in the previous section shows the seismic record and interpreted cross-section along the long-axis of Shag Rocks and Harding Rock.

The following Figures and Charts provide the results from the seismic survey over Shag Rocks:

- Figure 4-19 is an isopach map (scale 1"=200') contoured at 5' intervals that shows the estimated thickness of unconsolidated sediment on and around Shag Rocks. These isopach contours are also presented in Appendix C as a full-size chart at scale 1"=100' (Chart C-4).
- Figure 4-20 is a bedrock elevation map (scale 1"=200') referenced to MLLW. The bedrock elevation map is contoured at 5' intervals and shows the estimated elevation of the top of bedrock near Shag Rocks. This bedrock elevation map is also presented in Appendix C as a full-size chart at scale 1"=100' (Chart C-5).

The surficial sediment varies in thickness from 0-100' with the thickest deposit located towards the southern end of the site (Figure 4-19). The sediment between Harding and Shag Rocks are relatively thin (approximately 5' to 25') and overlie a ridge structure connecting the two rock masses (Figure 4-13).

The elevation of the top of bedrock varies from elevation -38' to -200' MLLW (Figure 4-20). The southern end of the rock mass drops off rapidly relative to the flanks and the shallow ridge connecting Harding Rock. The compressional velocities measured at Shag Rocks ranges from 10,000 to 10,700 feet/second (Table 4-3).

TABLE 4-3: Compressional Velocities Recorded by the Seismic Refraction Survey at Shag Rocks on 2-5 October 2000.

Array	Easting	Northing	Velocity (ft/sec)
S1	6,001,163'	2,132,095'	10,700
S2	6,001,518'	2,132,196'	10,000
S3	6,001,679'	2,131,686'	10,600

4.4 ARCH ROCK

Arch Rock is located approximately 1,500' south of Shag Rocks and 4,500' west of Alcatraz Island. Arch Rock had its top removed to below elevation -30' MLLW in the early 1900's. Arch Rock was again blasted in the 1930's to below elevation -35' MLLW.

The following Figures and Charts present the results from the hydrographic surveys over Arch Rock:

- Figure 4-21 is a bathymetric contour chart of Arch Rock at scale 1"=200'.

- Figure 4-22 shows 3-dimensional views of Arch Rock as seen from above, the north, and the south.
- In Appendix D, Chart D-1 presents the bathymetric contour chart and three 3-dimensional views of Arch Rock as imaged from above, the north and the south at scale 1"=100'.
- Chart D-2 in Appendix D is a bathymetric contour chart (scale: 1"=50') showing soundings in a 10' x 10' square grid directly over Arch Rock.

Arch Rock is a rock mass with a flattened top that rises about 40' above the surrounding seafloor. The elevation of the seafloor around Arch Rock is approximately -70' to -80' MLLW, except for a depression exceeding elevation -100' MLLW on the northwest corner of the Rock. Most of Arch Rock's flattened top is at elevation -38' MLLW, but there are several small peaks or boulders on top that extend up to elevation -36' MLLW.

Two ridges extend from the northwest flank of Arch Rocks. One ridge rises about 15' above the surrounding seafloor and extends towards the northwest from the rock mass. The second ridge is smaller (approximately 7' above the surrounding seafloor), oriented towards the north, and is physically separated from the main rock mass.

The surface area of Arch Rock above elevation -55' MLLW is approximately 461,100 square feet.

In Appendix D, Chart D-3 shows the side-scan sonar records presented as a mosaic at scale 1"=100'. The side scan mosaic clearly shows a mass of exposed rock, surrounded by unconsolidated sediments. Well-defined sandwaves located north and west of Arch Rock suggest coarse-grain sediments on the seafloor. The seafloor appears to be smooth or has small sandwaves to the east and south of Arch Rock, suggestive of fine-grained sediments. A single 15' high ridge of at least 500'-length leads from edge of Arch Rock towards the northwest.

The side-scan records also show several targets that are man-made. A 230'-long cable is visible on the side-scan records that leads from the eastern flank of Arch Rock towards the northeast to a seafloor object near the base of the Rock. This seafloor object is approximately 25' x 30' in size, but its identity is unknown. Deep gouges (10-15' across and 300'-700' long) in the unconsolidated seafloor are visible on the side-scan records to the east of Arch Rock. These gouges in the seafloor may possibly be anchor scours.

Figure 4-23 presents the results of the magnetometer survey over Arch Rock. Two large magnetic targets are located near the top of Arch Rock; one target has a positive and negative magnetic anomaly of 90 gamma, while the second target has a magnetic signature of 100 gamma and -330 gamma relative to the Earth's magnetic field. The source of the ferrous metal creating these two magnetic anomalies is unknown. However, the location of these 2 large magnetic targets suggest they may be relics from past rock removal operations, or relics from drilling activities conducted on behalf of the U.S. Navy in support of a proposed magnetic degaussing facility on Arch Rock (Subsurface Consultants, 1985).

The seismic survey over Arch Rock collected a grid of subbottom profiles oriented both north-south and east-west. Figures 4-24 and 4-25 show the seismic record and interpreted cross-sections over Arch Rock in perpendicular orientations.

The following Figures and Charts present the interpreted results from the seismic survey over Arch Rock:

- Figure 4-26 is an isopach map (scale 1"=200') contoured at 5' intervals that shows the estimated thickness of unconsolidated sediment on and around Arch Rock. These isopach contours are also presented in Appendix D as a full-size chart at scale 1"=100' (Chart D-4).
- Figure 4-27 is a bedrock elevation map (scale 1"=200') referenced to MLLW. The bedrock elevation map is contoured at 5' intervals and shows the estimated elevation of the top of bedrock near Arch Rock. This bedrock elevation map is also presented in Appendix D as a full-size chart at scale 1"=100' (Chart D-5).

The surficial sediment layer ranges in thickness from 0-130' and increases rather uniformly in thickness around the rock mass. However, in the northeast corner of the site the sediment increases in thickness more rapidly where the bedrock is steep (Figure 4-26).

The elevation of the top of bedrock varies from elevation -38' to -200' relative to MLLW. The bedrock drops off rapidly north and east of the rock mass and very gradual to the south and west (Figure 4-27).

The seismic refraction velocity of the bedrock generally varied from 10,400 to 11,000 feet/second. However, of the four refraction measurements taken over Arch Rock, one had a lower value of 9,300 feet/second. This lower velocity, located in the center of three replicate shots oriented toward the southwest over the Rock, suggests localized fracturing of the bedrock.

TABLE 4-4: Compressional Velocities Recorded by the Seismic Refraction Survey at Arch Rock on 2-5 October 2000.

Array	Easting	Northing	Velocity (ft/sec)
A1	6,001,195'	2,130,321'	10,400
A2	6,001,482'	2,130,253'	10,650
A3	6,001,281'	2,130,177'	9,300
A4	6,001,071'	2,130,033'	11,000

4.5 GOLDEN GATE MOUND

This marine geophysical investigation mapped a unique underwater geological feature located approximately 0.5 miles west of Shag Rocks and 1.5 miles east of the Golden Gate. Nautical Chart No. 18649 shows the area to be above elevation -50' MLLW.

Informally called "*Unnamed Rock*" in the past, this Report proposes the name "*Golden Gate Mound*" as more appropriate. The geologic nature of the two ridge-like features is unknown, but they are possibly semi-consolidated sedimentary features or underwater sand dunes.

The following Figures and Charts present the results from the hydrographic survey:

- Figure 4-28: bathymetric chart of Golden Gate Mound, contoured at 5' intervals and plotted at scale 1"=200'
- Figure 4-29: 3-dimensional perspectives of Golden Gate Mound as viewed from above, from the north, and from the south.

- Chart E-1 in Appendix E: one bathymetric contour chart and three 3-dimensional views of Golden Gate Mound as imaged from above, the north and the south are presented at scale 1"=100'.
- Chart E-2 in Appendix E: a bathymetric contour chart at scale: 1"=50' showing soundings in a 10' x 10' square grid directly over Golden Gate Mound.

The bathymetric feature that this Report calls Golden Gate Mound is a pair of steep, sharply pointed, parallel ridges oriented towards the northwest. The two ridges rise about 30' above the surrounding seafloor, and the western ridge is higher than the eastern ridge by about 4'. The western ridge rises to an elevation of about -55' MLLW (-55.2' with multibeam and -54.8' with single-beam in same area). In between the two ridges is a trough that extends down to elevation -86' MLLW at the southeast end, -82' MLLW on the northwest end, and -75' MLLW in the middle.

The two ridges come together sharply at the southeast end to form a single ridge along the 70' depth contour. To the northwest, the ridges end without connecting. The deepest area surveyed is the north corner of the site at elevation -95' MLLW.

In Appendix E, Chart E-3 shows the side-scan sonar records presented as a mosaic at scale 1"=100'. The side scan mosaics show a relatively featureless seafloor at Golden Gate Mound, except for the top of the ridges and nearby sand waves. The composition of Golden Gate Mound is unknown, but a featureless seafloor is usually indicative of fine-grained sediment**.** Large amplitude sand waves are visible in the northwest corner of the survey area, which is indicative of coarse-grained sediments. Small-amplitude sand waves are visible climbing the west slope of the eastern ridge of Golden Gate Mound.

The results from the magnetometer survey at Golden Gate Mound (Figure 4-30) found no significant anomalies.

The seismic survey revealed two prominent ridge-like features oriented northwest to southeast. Figures 4-31 and 4-32 are representative seismic cross-sections across the two ridges. Several flatlying reflectors occur on the reflection records beneath the two ridges, which implies that the ridges are not bedrock.

Interpretation of the seismic records resulted in the following Figures and Charts:

- Figure 4-33 is an isopach map (scale 1"=200') contoured at 5' intervals that shows the estimated thickness of unconsolidated sediment on and around Golden Gate Mound. These isopach contours are also presented in Appendix E as a full-size chart at scale 1"=100' (Chart E-4).

- Figure 4-34 is a bedrock elevation map (scale 1"=200') referenced to MLLW. The bedrock elevation map is contoured at 5' intervals and shows the estimated elevation of the top of bedrock near Golden Gate Mound. This bedrock elevation map is also presented in Appendix E as a full-size chart at scale 1"=100' (Chart E-5).

In addition to the grid of seismic survey lines over Golden Gate Mound, a long subbottom profile was collected from this site to Arch Rock in order to confirm that the deepest reflector on the seismic records is the top of bedrock. The top of bedrock under Golden Gate Mound ranges in elevation from -135' to over -300' MLLW (Figure 4-34).

The seismic refraction survey at Golden Gate Mound used a longer hydrophone array than at the other sites. A longer hydrophone obtains deeper refraction data, and using a longer hydrophone can determine if one of the subsurface, horizontal reflectors is the top of bedrock. This longer array should detect the high velocity bedrock to a maximum subsurface depth of approximately 100'. However, the refraction data from both the long and short array indicated a compressional velocity of 5,000 to 5,100 feet/second (Table 4-5), which is typical for saturated marine sediment. Hence, no bedrock was found within 100' of the seabed.

An attempt to obtain a refraction velocity along the ridge-like structure yielded similar velocity values (5,000 feet/second). This suggests that these structures are not rock, but possibly underwater sand dunes. However, the ridge-like features are quite narrow making it very difficult to obtain data along their primary axis. It is quite possible that the values obtained during the seismic refraction survey represent the velocity of the marine sediment on the seafloor and not within the narrow ridge in question.

TABLE 4-5: Compressional Velocities Recorded by the Seismic Refraction Survey at Golden Gate Mound on 2-5 October 2000.

Array	Easting	Northing	Velocity (ft/sec)	Comments
G1	5,998,386'	2,130,475'	5,000	Sediment
G2	5,998,639'	2,130,486'	5,100	Sediment
G3	5,998,912'	2,130,501'	5,000	Sediment
G4	5,998,562'	2,130,214'	5,100	Sediment
G5	5,998,887'	2,130,213'	5,000	Sediment
G6	5,998,682'	2,130,035'	5,000	Sediment
G7	5,999,039'	2,129,782'	5,100	Sediment

5. CONCLUSIONS

The full-size charts contained within this Report present the results from the marine geophysical investigation in support of the San Francisco Bay Rocks Removal Project. This section summarizes the conclusions reached by reviewing the charts and data contained within this Report:

- Based on a rigorous QA/QC plan that controlled, assessed and measured the quality of data collected, it is concluded that the data contained within this Report is suitably accurate for utilization in planning the future geotechnical programs related to the Rocks Removal Project. The bedrock elevation contour charts contained within this Report should be reviewed, and amended if necessary, after completion of the future geotechnical program.

- Blossom Rock, Arch Rock, Harding Rock, and Shag Rocks rise above elevation –40' MLLW and are potential hazards to deep draft shipping.

- Four of the five sites surveyed are exposed rock masses that rise above the unconsolidated sediments on the seafloor of Central San Francisco Bay. The side-scan sonar clearly shows exposed bedrock at each of these four sites (Harding, Shag, Arch and Blossom Rocks). The seismic reflection survey shows a maximum subsurface penetration of approximately 180' below the seabed and clearly identifies the top of bedrock. The seismic reflection survey shows the bedrock rising from the unconsolidated sediments, but was not able to penetrate the rock masses. The seismic refraction data indicates that the compressional velocity for these rock masses is approximately 10,500 feet/second, which is indicative of tight, strong rock. Further, the compressional velocity at Harding Rock, Shag Rocks, Arch Rock, and Blossom Rock infer that: 1) these rocks may have similar properties and 2) these rocks can not be removed using conventional dredging equipment.

- Pockets of unconsolidated sediments are present on top and/or along the flanks of Harding Rock, Shag Rocks, Arch Rock, and Blossom Rock. Coarse-grained sediment or rubble that appears on the seismic reflection and side-scan records is the probable cause of several lower compressional velocity values.

- Previously called "*Unnamed Rock*" informally, this Report proposes the name "*Golden Gate Mound*" for the fifth site investigated. Golden Gate Mound is not a rock mass, but probably is a semi-consolidated sedimentary feature or underwater sand dune. The seismic reflection survey shows no evidence of shallow bedrock within 60' of the seafloor. Seismic refraction over the twin ridges at Golden Gate Mound reveals a compressional velocity of approximately 5,100 feet/second, which is indicative of unconsolidated marine sediment. The side-scan sonar records show featureless slopes with no evidence of exposed rock.

- At present, Golden Gate Mound is below elevation -55' MLLW and it is probably not a hazard to navigation. In addition, Golden Gate Mound is not a rock mass. It is therefore recommended that Golden Gate Mound be considered for deletion from any future investigations in support of the San Francisco Bay Rock Removal Project.

- Although Golden Gate Mound is not a rock mass and presently is not a hazard to navigation, there is evidence that the Mound may be a transient geologic feature that is subject to changes in location, height and shape. The NOAA nautical chart #18649 shows Golden Gate Mound had an elevation of -48' MLLW during the 1970's, and the 1998 USGS survey showed the shape and location of Golden Gate Mound to be significantly different. For a better understanding of the Mound morphology, it is recommended that: 1) sediment cores be taken along the twin ridges of Golden Gate Mound to assess the character and dredgability of the sediments, and 2) hydrographic surveys be conducted periodically to monitor the changes in the shape, size, and height of Golden Gate Mound. It is conceivable that the size, shape, and height of Golden Gate Mound may be controlled by the tidal current flowing past Harding Rock, Shag Rocks, and/or Arch Rock, and that removal of these rocks could have an unknown impact on the Mound and sediment transport within the Bay.

- Depressions near the base of the Rocks may indicate scouring of sediments caused by currents.

- Numerous pinnacles are present around Shag Rocks, and one pinnacle located east of the Rock rises above elevation -50' MLLW.

- Numerous fish, ranging from schools of baitfish in the water column to larger fish near the rocky bottom, occasionally interfered with the side-scan sonar and hydrographic surveys.

- Marine vegetation growing on the Rocks was typically not visible on the sonar records, but marine vegetation may be possible on the rocky substrate.

- The NOAA tide gauge located at the Presidio provides water surface elevation for Central San Francisco Bay via the Internet. The NOAA tide gauge can provide accurate tidal information for the San Francisco Bay Rocks Removal Project only during periods of neap tides when there is minimal change in water surface elevation across San Francisco Bay. This study documents that hydrographic surveys over the 5 offshore sites in Central San Francisco Bay can be accurate using the NOAA tide gauge, but only during periods of neap tides. Hydrographic surveys at the offshore sites should not be conducted during periods when tides change more than 3'-4' between high and low tide, because NOAA's tide data may be incorrect for the offshore sites by 1' or more.

- Several magnetometer and side-scan sonar targets are on or near most Rocks, and an archaeologist should investigate these targets before the beginning of rock removal activities.

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